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Advanced Research On Air Traffic Flow

Publication Citations

Journals and Book Articles:

Odoni, A. R., "Issues in Air Traffic Flow Management", chapter in Advanced Technologies for Air Traffic Flow Management, H. Winter and H.G. Nusser, editors, Springer-Verlag, Berlin, pp. 43-63, 1994.

Bertsimas, D. and S. Stock, "Air Traffic Flow Management in the Presence of En Route Capacity Constraints", accepted for publication in Operations Research (to appear 1998).

Adams, Milton, S. Kolitz, J. Milner and A. R. Odoni, "Evolutionary Concepts for Decentralized Air Traffic Flow Management", Air Traffic Control Quarterly, 4, pp. 281-307, 1996.

Shumsky, Robert, "Optimal Updating of Forecasts", accepted for publication in Management Science (to appear 1998).

Theses and Dissertations:

Shumsky, Robert, "Dynamic Statistical Models for Predicting Flight Takeoff Times for the Enhanced Traffic Management System", Ph.D. dissertation, August 1995.

Sheel, Mina "A Stochastic Optimization Model for Air Traffic Ground Holding", S.M. thesis, September 1996.

Stock, Sarah, "Advanced Flow Management on a Capacitated ATC Network", Ph.D. dissertation, June 1997.

Milner, Joseph, "An Approach for Dynamic, Real-Time Landing Slot Allocation with Airline Participation", Ph.D. dissertation, June 1995.

Guastalla, Guglielmo, "Efficient Heuristics for Air Traffic Flow Management", S.M. thesis, June 1997.

Carlson, Paul, "Dynamic Airline Slot Allocation in Hub Airports", S.M. thesis, June 1997.

Ying, Kalvin, "A Model to Estimate the Benefits of Improved Weather Prediction for Air Traffic Flow Management" (co-supervised with A. I. Barnett) September 1995.

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Paul Carlson, Master's student, graduated 1997.

Guglielmo Guastalla, Master's student, graduated 1997.

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Allocating Banks of Flights to Arrival Slots in Reduced-Capacity Situations

by

Paul M. Carlson

Submitted to the Department of Civil and Environmental Engineering
on May 9, 1997, in partial fulfillment of the
requirements for the degree of
Master of Science in Transportation

Abstract

To date, the decision support models developed to assist an airline that is facing disruption of its normal operating schedule have, with very little exception, ignored the special consideration that operations at hub airports require. Instead of considering the dependencies induced by flights full of connecting passengers, models have incorrectly tended to view the passengers of these flights as either terminating at the hub, or continuing on the same flight (through passengers). In addition, the objective function of many models is based solely on customer service metrics, a situation at odds with the airline as a profit-maximizing organization.

Due to the two limitations just described, we believe that the existing models are of limited use to airlines who seek to maximize profit by operating a schedule of flights over a hub-and-spoke network. Unfortunately, this describes the majority of the large U.S. airlines.

In this research we present a series of three mixed integer models that are free from the above limitations. We then test and compare the models using a real-world scenario involving over 300 flights spanning 14 hours. One model stands out and is able to solve the real-world scenario in real time. In addition, we present an extensive literature review and classification of the decision support models developed to assist an airline facing schedule disruption.

Thesis Supervisor: Amedeo Odoni
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A Dynamic Approach for Air Traffic Flow Management of Arriving Aircraft at a Congested Airport

by

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Submitted to the Department of Aeronautics and Astronautics in Partial Fulfillment of the Requirements for the Degree of

Masters of Science in Aeronautics and Astronautics

Abstract

Both the airline industry and air travelers have been pummeled by increased delays experienced at major airports and, as a result, rising operating costs. In this thesis, we focus on the dynamic Arrival Flow Management sub-process of the more general Congestion Management process at a given airport. We show the inefficiencies of a current approach, Miles-In-Trail, and present and evaluate a new approach which we have called Integrated Interactive Dynamic Flow Control (IIDFC). IIDFC produces a set of Traffic Flow Management Advisories which are dynamically updated. It integrates all types of Traffic Flow Advisories and is interactive in the sense that the set of advisories generated and actually issued can be modified by Traffic Flow Managers. Given the complexity of the overall flow management problem, a Traffic Flow Management Simulator was implemented as part of this thesis in order to evaluate various dynamic flow control strategies.

Thesis Supervisor: Robert W. Simpson

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An Advanced Algorithm for Air Traffic Flow Management

by

Guglielmo Guastalla

Submitted to the Department of Electrical Engineering and Computer Science
on 22 May 1997, in partial fulfillment of the
requirements for the degree of
Master of Science in Operations Research

Abstract

The increasing volume of air traffic in recent years has led to heavier use of airports and airways, while their capacities have not grown accordingly. This leads to a situation of congestion in air traffic networks, with departure delays and queues before landing, causing great economic losses to air carriers and potentially affecting air traffic safety. A way of reducing congestion is to adopt a Ground Holding policy, i.e., delay some aircraft before departure in order to avoid airborne delay. This thesis focuses on the static/deterministic Multi Airport Ground Holding Problem (MAGHP) under the assumption of insufficient capacities at arrival airports. Different approaches for the solution of the MAGHP are presented: (i) three alternative integer linear programming models; (ii) a heuristic algorithm based on priorities; (iii) a new algorithm based on the integration of the heuristic algorithm with one of the integer linear programming models. A comparison of their performance based on 39 test cases is provided. The integrated algorithm provides exact solutions in a much shorter time than previous algorithms proposed in the literature.

Thesis Supervisor: Amedeo R. Odoni
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Dynamic Slot Allocation with Airline Participation

by

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Submitted to the Sloan School of Management
on May 24, 1995, in partial fulfillment of the
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Doctor of Philosophy in Operations Research

Abstract

Flights are delayed every day because of short-term reductions in the capacity of airports. When Air Traffic Control (ATC) anticipates that the capacity of an airport will be insufficient, it allocates the available capacity by assigning to each scheduled flight a time at which it may arrive. We refer to this time, plus a small window around it, as a dynamic slot. The allocation is made on a First Come/First Serve (FCFS) basis according to the schedule of flights. In this thesis, we investigate methods for allowing greater participation by the airlines in dynamic slot allocation and show that doing so can result in a more efficient use of available airport capacity.

We describe an auction which can be used to allocate the dynamic slots based on bids provided by the airlines. We propose that the airlines bid using a fiat money, the budgets of which are updated according to each day's allocation. We show that the auction may result in fair and optimal allocations. We develop a trading mechanism by which airlines can exchange slots.

We develop the Bank Delay model which minimizes the total delay passengers encounter when traveling through a hub airport. We present an Indexing heuristic and a Lagrangian heuristic for solving the model. The Indexing heuristic provides near optimal allocations quickly. We show that the Bank Delay model results in significant savings over the FCFS allocation.

We develop models to assist airlines in responding to dynamic slot allocations. We develop the Independent Flights model which describes how airlines may assign flights to slots at origin/destination airports and develop the Cancellation/Delay model which addresses the bank structure of flights scheduled into hub airports. A dynamic program is presented which solves the latter by decomposing the problem into a sequence of single bank problems.

We develop the Network Cancellation/Delay model which describes how an airline may respond to several slot allocations in a hub-and-spoke network. Delays are propagated throughout the network. We present an integer programming formulation and describe a set of valid inequalities for it. We solve moderate sized problems using branch and bound.

Thesis Supervisor: Dimitris J. Bertsimas
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Dynamic Flow Management Problems in Air Transportation

by

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Submitted to the Department of Electrical Engineering and Computer Science
on May 23, 1997, in partial fulfillment of the
requirements for the degree of
Doctorate of Philosophy in Operations Research

Abstract

In 1995, over six hundred thousand licensed pilots flew nearly thirty-five million flights into over eighteen thousand U.S. airports, logging more than 519 billion passenger miles. Since demand for air travel has increased by more than 50% in the last decade while capacity has stagnated, congestion is a problem of undeniable practical significance. In this thesis, we will develop optimization techniques that reduce the impact of congestion on the national airspace. We start by determining the optimal release times for flights into the airspace and the optimal speed adjustment while airborne taking into account the capacitated airspace. This is called the *Air Traffic Flow Management Problem (TFMP)*. We address the complexity, showing that it is NP-hard. We build an integer programming formulation that is quite strong as some of the proposed inequalities are facet defining for the convex hull of solutions. For practical problems, the solutions of the LP relaxation of the TFMP are very often integral. In essence, we reduce the problem to efficiently solving large scale linear programming problems. Thus, the computation times are reasonably small for large scale, practical problems involving thousands of flights. Next, we address the problem of determining how to reroute aircraft in the airspace system when faced with dynamically changing weather conditions. This is called the *Air Traffic Flow Management Rerouting Problem (TFMRP)* .We present an integrated mathematical programming approach for the TFMRP, which utilizes several methodologies, in order to minimize delay costs. In order to address the high dimensionality, we present an aggregate model, in which we formulate the TFMRP as a multicommodity, integer, dynamic network flow problem with certain side constraints. Using Lagrangian relaxation, we generate aggregate flows that are decomposed into a collection of flight paths using a randomized rounding heuristic. This collection of paths is used in a packing integer programming formulation, the solution of which generates feasible and near-optimal routes for individual flights. The algorithm, termed the Lagrangian Generation Algorithm, is used to solve practical problems in the southwestern portion of United States in which

the solutions are within 1% of the corresponding lower bounds.

Thesis Supervisor: Dimitris J. Bertsimas
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Probabilistic Analysis of Ground-Holding Strategies

by

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Submitted to the Sloan School of Management
on September 20, 1996, in partial fulfillment of the
requirements for the degree of
Master of Science in Operations Research

Abstract

The Ground-Holding Policy Problem (GHPP) has become a matter of great interest in recent years because of the high cost incurred by aircraft suffering from delays. Ground-holding keeps a flight on the ground at the departure airport if it is known it will be unable to land at the arrival airport. The GHPP is determining how many flights should be held on the ground before take-off and for how long, in order to minimize the cost of delays. When the uncertainty associated with airport landing capacity is considered, the GHPP becomes complicated. A decision support system that incorporates this uncertainty, solves the GHPP quickly, and gives good results would be of great help to air traffic management.

The purpose of this thesis is to modify and analyze a probabilistic ground-holding algorithm by applying it to two common cases of capacity reduction. A graphical user interface was developed and sensitivity analysis was done on the algorithm, in order to see how it may be implemented in practice. The sensitivity analysis showed the algorithm was very sensitive to the number of probabilistic capacity scenarios used and to the cost ratio of air delay to ground delay. The algorithm was not particularly sensitive to the number of periods that the time horizon was divided into. In terms of cost savings, a ground-holding policy was the most beneficial when demand greatly exceeded airport capacity. When compared to other air traffic flow strategies, the ground-holding algorithm performed the best and was the most consistent under various situations. The algorithm can solve large problems quickly and efficiently on a personal computer.

Thesis Supervisor: Amedeo R. Odoni
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Dynamic Statistical Models for the Prediction of Aircraft Take-off Times

by

Robert Arthur Shumsky

Submitted to the Department of Electrical Engineering and Computer Science on June 16, 1995, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Operations Research

Abstract

Safe and efficient management of air traffic requires accurate predictions of aircraft trajectories. In the existing air traffic system, predictions of take-off times are a major source of forecast error. This thesis presents three primary contributions: forecasting models for predicting individual take-off times, models of aircraft flow to predict departure congestion at major airports, and methods for balancing the frequency of forecast updates with the costs of forecast inaccuracy. The models use real-time data to update parameters and generate forecasts. They are tested with data from the existing air traffic management system as well as data that may be obtained from other sources, such as the commercial air carriers.

Empirical tests using data specific to Logan Airport suggest that the take-off time forecasting models achieve small improvements in forecast accuracy over existing methods when using information currently available to the air traffic management system. If additional, carrier-specific information is available, the models achieve more substantial improvements. Empirical tests also demonstrate that the departure flow models produce accurate predictions of airfield congestion over both ten-minute and one-hour forecast horizons.

Once a take-off time forecast is produced, there are frequent opportunities to update the prediction with new information. We develop forecasting algorithms which balance prediction accuracy and the cost of each forecast update, for frequent updates burden the traffic management system's computers and lead to distrust in a system that cannot 'make up its mind.' Numerical examples demonstrate that the proposed algorithms significantly improve forecast accuracy and require fewer updates than existing procedures.

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How Can Improved Weather Forecasting Accuracy Reduce Air Traffic Delays?

by

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Submitted to the Department of Electrical Engineering and Computer Science
on June 30, 1995, in partial fulfillment of the
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Master of Science in Operations Research

Abstract

In the recent years, air traffic congestion has created national cost of $5.1 billion per year. Among all possibilities to reduce air traffic delays, a short-term approach attempts to control air traffic flow to match the demand with available capacity at commercial airports. In the spirit of this practice, this thesis addresses whether improved weather forecasting accuracy can reduce air traffic delays. A major effort of this study includes the development of a simulation model to explore the subject with arrival flight information into Boston's Logan Airport. The simulator generates weather transition, under which air traffic delays are estimated. We assume that Logan could use perfect and partially perfect weather information at the scheduled departure time of a flight to predict when the airplane will land at the airport. With the assumption that a minute of delay in the air is twice as "expensive" as a minute on the ground at the airport of origin, Logan could apply a ground-hold policy to the airplane for the exact amount of time that it is predicted to spend in the air. Thus, the flow into Logan is controlled, and air traffic delays are reduced. The benefits of improved weather forecasting abilities to air traffic delays are also measured. Our study shows that both perfect and partially perfect weather forecasts can reduce air traffic delays and costs.

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